Phenology of western flower thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on plant species in and near apple orchards in Washington State

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ABSTRACT

Both orchard and adjacent native vegetation harboured adult western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), from early spring until fall. *Frankliniella occidentalis* made up the great majority of adults collected in flowers of most plant species sampled, including apple. Other species found on apple flowers included *Anaphothrips obscurus* Müller, which lives on grasses, and *Thrips brevipilosus* Moulton. A mixture of thrips species, including *F. occidentalis*, *Scirtothrips citri* (Moulton), *Thrips tabaci* Lindeman, and *Thrips treherni* Preisner, occurred on apple shoots. Thrips were found in orchards as early as green tip (early April), with the highest concentrations of *F. occidentalis* in shoots occurring in June and July. Thrips declined in late summer as shoots formed dormant buds; however, some *F. occidentalis* adults were still found in early September. Five common woody plants and forbs selected for sampling in the sagebrush-steppe habitat had *F. occidentalis* adults present, especially during bloom. Western flower thrips can exploit open flowers or young shoots from spring through fall in native vegetation because of the diversity of plants and their different growth habits.

INTRODUCTION

Western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is native to western North America, where it has long been a crop pest (Bailey 1940). In the latter half of the 1900s, it spread to various crops, greenhouse cultures, and native plants in other areas of North America, where it became one of the most common thrips species (Felland *et al.* 1993, Chellemi *et al.* 1994). During the same period it also spread to native and cultivated habitats throughout the world (Kirk and Terry 2003). *Frankliniella occidentalis* is attracted to showy, fragrant flowers of numerous species (Terry 1997), but also feeds on wheat (Toapanta *et al.* 1996).

Frankliniella occidentalis is a pest of apple, where it oviposits on developing fruitlets around the flowering period (Terry 1991, Beers *et al.* 1993). Oviposition sites on fruit develop scar tissue surrounded by a larger, pinkish-white surface discoloration called a pansy spot. This damage is most apparent on green or light-coloured apple cultivars (Venables 1925); not all cultivars show the damage at harvest. After flowers are no longer available, additional generations develop in the apical portions of growing apple shoots (Venables 1925).

The cause of pansy spot was unknown for many years after it was first noted in the early 1900s, until Newcomer (1921) made detailed observations and found thrips to be the cause. However, in the original work, the species was not identified. Venables (1925) was the first to identify the species associated with apple. Although *F. occidentalis* is cited as the most likely cause of injury to apple, Venables also found *Aeo-*

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lothrips fasciatus (L.), *A. conjunctus* Pergande, and *Taeniothrips* sp. He notes, however, that the latter species are likely predacious on *F. occidentalis*. Childs (1927) positively implicated both *F. occidentalis* and *A. fasciatus* as causing injury, even though he later notes that *A. fasciatus* was supposed to be predacious and was not common. Madsen and Jack (1966) list *F. occidentalis*, *Rhopaloandrothrips corni* Moulton, *Thrips hukkineni* Priesner (=*T. trehernei* Priesner), *Thrips tabaci* Lindeman, *Haplothrips niger* Osborne, and *Leptothrips mali* (Fitch) as occurring on apple, with the latter two species as probable predators. The leaf-feeding species *T. tabaci* was considered a visitor from grass hosts. Pearsall and Myers (2001) note that 12 species of thrips were found in nectarine orchards in central British Columbia, Canada, again with *F. occidentalis* as the most common species. An investigation of the species inhabiting apple has not been done in the fruit-growing regions of central Washington.

The possible influence of plant species in or near the orchard on potential damage by thrips was first suggested by Venables (1925). He noted that alfalfa was a host, and that its common use as a cover crop might contribute to thrips damage. This idea was expanded by Madsen and Jack (1966), who sampled thrips on a variety of native plants commonly found near apple orchards in the dry interior valleys of British Columbia. They concluded that *F. occidentalis* moves from host to host as the plants flower. In addition, they note the overlapping species complex between apple and native hosts. However, they present only a list of thrips species collected from various plant hosts, without temporal or quantitative information. Further studies were conducted in the mid-1990s (Pearsall and Myers 2000a, 2000b, Pearsall and Myers 2001) that examined thrips ecology and dispersal in orchards near native habitat in central British Columbia. These authors concluded that thrips abundance in nectarine orchards was related to dandelion density, and to proximity of native habitat. The role of weeds on the orchard floor and native plants in extra-orchard habitats has not been investigated in central Washington. This information is foundational to the development of effective pest management strategies.

The work herein has two objectives. The first objective is to determine the species of thrips adults in apple flowers and shoots in central Washington state. The second is to determine if and when selected weed and native plant species are inhabited by the adults.

MATERIALS AND METHODS

Four 'Granny Smith' apple orchards near the towns of Vantage (Kittitas County), Orondo (Douglas County), Brewster (Okanogan County), and Bridgeport (Douglas County) in central Washington were selected as study sites and sampled in 2002. All sites were typical of apple orchards in the Columbia River valley in that they were irrigated regularly to maintain fruit trees in a climate that receives an average of 30-50 cm of precipitation per year, the majority as snowfall. Orchards were bordered by native vegetation on one or two sides. None of the sites was near riparian habitat.

The three northern sites, Orondo, Brewster, and Bridgeport, were adjacent to sagebrush-bunchgrass steppe. These areas had a mixture of grass species, including bluebunch wheatgrass, *Agropyron spicatum* (Pursh) Scribn. and J. G. Smith, and needlegrass, *Stipa* spp. Forbs and woody plants included arrowleaf balsamroot, *Balsamorhiza sagittata* (Pursh) Nutt., lupin, *Lupinus* spp., big sagebrush, *Artemisia tridentata* Nutt., and snow buckwheat, *Eriogonum niveum* Douglas ex Berth. Patches of plants characteristic of higher elevations were also present, such as western yellow pine, *Pinus ponderosa* P and C Lawson, and antelope bitterbrush, *Purshia tridentata* (Pursh) DC. The orchards were

irrigated by sprinklers and had a stand of Italian ryegrass, *Lolium multiflorum* Lam. (Orondo site), orchardgrass, *Dactylis glomerata* (L.) (Bridgeport site), or weedy species such as downy brome, *Bromus tectorum* L. (Brewster site). All three sites had a mixture of broadleaf weed species on the orchard floor, including dandelion, *Taraxacum officinale* G. H. Weber ex Wiggers.

The Vantage site, the farthest south, was bordered by rocky soil and talus. Grasses included bluebunch wheatgrass and sandberg bluegrass, *Poa secunda* J. Presl. Forbs and woody species included phlox, *Phlox* spp., daisy, *Erigeron* spp., big sagebrush, and gray rabbitbrush, *Chrysothamnus nauseosus* (Pallas) Britt. The orchard was drip-irrigated and the soil surface was dry for most of the summer. The ground cover included dry-adapted species such as downy brome and flixweed, *Descurania sophia* (L.) Webb. ex Prantl.

The Orondo site was under organic management. No insecticides were used other than horticultural oil. All the other orchards were under conventional pest management. The Brewster site received no pesticides for thrips, and only azinphosmethyl during May through August. The Bridgeport site was treated with formetanate hydrochloride for thrips at full bloom, then pyriproxyfen and methoxyfenozide for lepidopteran pests. The Vantage site was treated with horticultural mineral oil and chlorpyrifos at green tip, and spinosad for thrips at full bloom.

The objective of sampling was to count adult thrips, presumed to be primarily *F. occidentalis,* concentrated on the preferred tissue (flowers and very young leaves) of the various plant species. Beginning in early March, after the snow had melted, samples were taken from apple trees, selected plants in the orchard ground cover, and plants located 10-50 m into surrounding uncultivated native vegetation. All samples were collected, placed in 15 × 15 cm self-sealing plastic bags, and immediately stored in a cooler. Additional details of sampling procedures are described by habitat.

Apple trees. As soon as the apple buds started to grow (green tip), 100 buds were taken weekly, or during bloom, twice per week, from each site. Flower bud samples and vegetative bud samples were taken separately. From king bloom to petal fall, 100 individual flowers, or, after petal fall, king fruit, were sampled. Vegetative bud samples were taken from actively growing shoots throughout the summer. These became scarce as the shoots completed growth later in the year. Sampling ended when growing tips could no longer be found, by late summer. A sample of 20 dormant shoots was taken at each site in October.

Ground cover. The two most common plant species on the orchard floor, one grass species and one broadleaf weed, were selected for sampling. The most common species varied by site. Grasses included Italian ryegrass, orchardgrass, and downy brome. Broadleaf weeds included dandelion and flixweed. Four replicate samples per site were collected weekly. Samples consisted of individual plants cut off at ground level, or when the plants were too large for the sample bags, the flower stalks or crowns containing the youngest leaf tissue were selected. Sampling was discontinued when the above-ground plant parts had dried due to dormancy, or in the case of annuals, had gone to seed and dried. Sampling began again when winter annuals began to sprout in the fall.

Sagebrush steppe. Three to four of the most common species of plants in the surrounding native vegetation were selected in the beginning for sampling. Four replicate samples were taken weekly. One of the species was a grass and the others were forbs or woody plants. Grasses included bluebunch wheatgrass, sandberg bluegrass, and needlegrass. Other plants included gray rabbitbrush, big sagebrush, antelope bitterbrush, arrowleaf balsamroot, and snow buckwheat. The sampling methods for grasses were the same as for those on the orchard floor. For large forbs and woody species, several shoot cuttings, about 15 cm long, were collected in sufficient quantity to

fill a sample bag. If available, cuttings with actively growing leaves or flowers were selected preferentially over dormant or non-flowering shoots.

Extraction of thrips. Thrips were separated from the plant material by filling the sample bag with water, adding a few drops of liquid detergent, and agitating for several seconds. Thrips and plant material were separated from the soapy water by pouring through two sieves (Hubbard Scientific Co., Northbrook, IL). The larger sieve (#10, 0.25 mm mesh) trapped most of the plant material, and the finer sieve (#230, 0.0014 mm mesh) trapped the thrips (Lewis *et al.* 1997a) Thrips were then rinsed into a vial of 50% ethanol.

Adult and larval thrips were counted separately. Adult specimens from apple flowers were all slide-mounted in PVA Mounting Medium (BioQuip Products, Inc., Rancho Dominiguez, CA) and identified. The small number of species was sent to Cheryl O'Donnell, Department of Entomology, University of California, Davis, CA, as vouchers for identification. Adult *Frankliniella* specimens from apple shoots and other plant species were slide-mounted and identified to species. A representative sample of the other species on apple shoots was also slide-mounted and sent to Cheryl O'Donnell for identification.

Most of the samples contained fewer than 50 specimens. However, a few samples, especially those from dandelion, contained an unusually high number of thrips, often exceeding 150. If the number of adult thrips exceeded 50, the total was recorded, and half of the specimens were randomly selected for a subsample. The original numbers of *F. occidentalis*, other species, and other unidentified thrips were estimated by dividing the numbers in the subsample by the proportion of adults selected.

RESULTS

Apple trees were still fully dormant when sampling began in early March. When the apple buds reached green tip, about the second week in April, adult thrips began to appear in the shoots (Fig. 1). Adult thrips were present in the opening apple flowers as petals began to unfurl (pink) (Brewster, Bridgeport, and Vantage sites) or by the time the first flowers in the clusters had fully opened (king bloom) (Orondo site). Larvae were also found at king bloom. By full bloom, both adults and larvae were abundant. Insecticide applications (formetanate hydrochloride and spinosad) reduced the numbers of adults and larvae, but only temporarily. Although thrips at the Vantage site may have been affected by the chlorpyrifos application at green tip, adults were found in blossom clusters by pink. Adults and larvae declined after full bloom, but a few were still present at the end of the blossom period. Some thrips were recovered from young fruit at petal fall.

Frankliniella occidentalis made up the great majority (90.3%) of the adults collected in apple flowers (Table 1). *Anaphothrips obscurus* Müller, a species found on grasses (Lewis *et al.* 1997b), made up 8.9%. *Thrips brevipilosus* Moulton, a species originally collected from native forbs, potential orchard weeds such as alfalfa and wild mustard, and a species of *Artemisia* (Moulton 1927), made up the remaining 0.8%. *Frankliniella occidentalis* comprised a little more than one-third of the adults collected from apple shoots (Table 1). *Thrips treherni* made up 12.7% of specimens, while *Scirtothrips citri* (Moulton) and *T. tabaci* together made up most of the remaining 49.5%.

Thrips numbers in apple shoots were low during bloom, then greatly increased at petal fall (mid-May) (Fig. 1). No apparent break occurred between one generation and the next. The highest concentrations of *F. occidentalis* in shoots occurred in June and July. Larvae outnumbered adults in May, June, and part of July. Adult and larval populations declined in late summer as shoots formed dormant buds; however, some *F. occidentalis* were still found in early September (Fig. 1). Samples of the

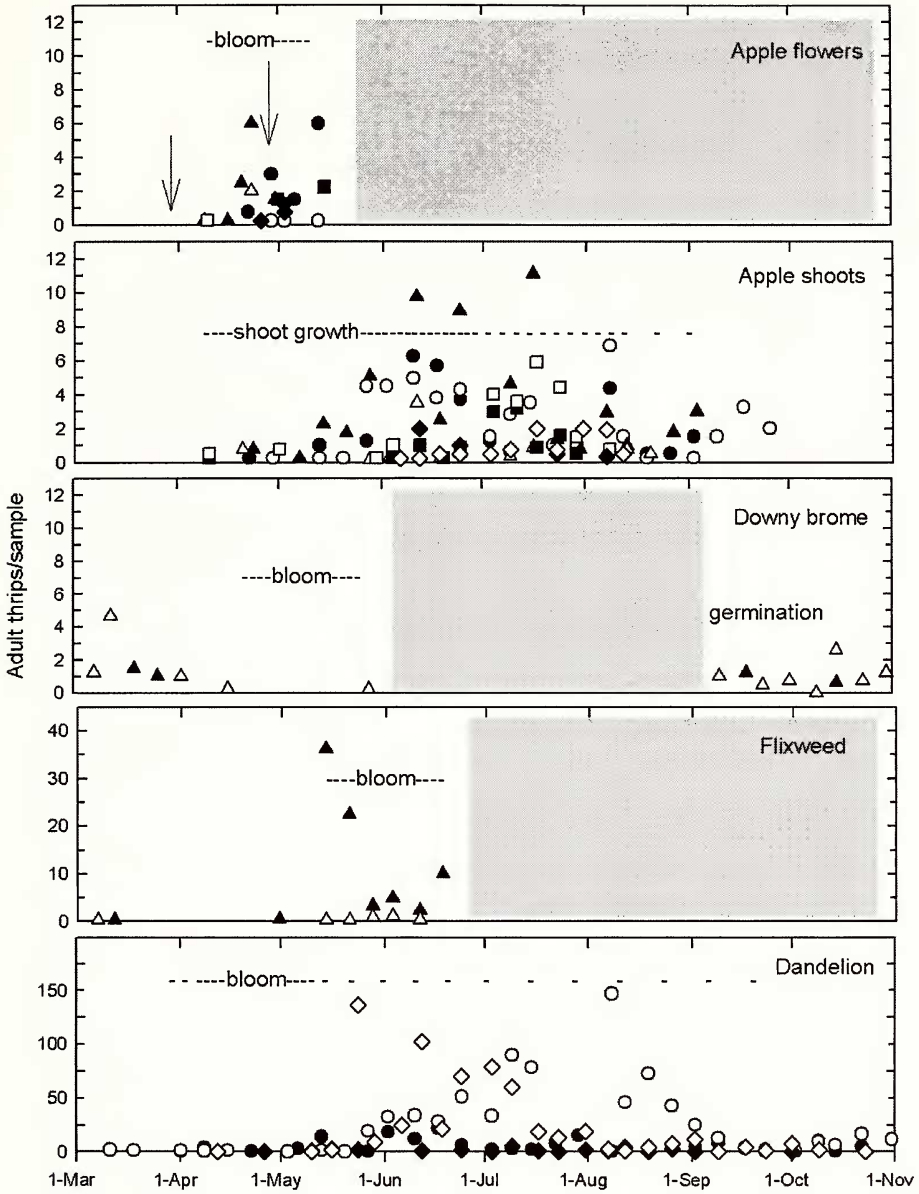

Figure 1. Adult *Frankliniella occidentalis* (solid symbols) and other thrips species combined (open symbols) found in plant samples in orchards near Brewster (●), Vantage (▲), Bridgeport (■), and Orondo (♦) in 2002. Periods of plant growth are indicated with dashed lines. A gray background shows a period when samples were not taken. Samples with zeros are not represented. Arrows indicate the date of application of chlorpyrifos at the Vantage site (pre-bloom) and formetanate hydrochloride or spinosad at the Bridgeport and Vantage sites (full bloom).

dormant buds in October yielded a few specimens of other species at one site.

Few thrips specimens were found in orchardgrass or Italian ryegrass, and no *F. occidentalis* adults were found on these species. A few unidentified larvae were found on both species in the fall. *Frankliniella occidentalis* adults were found on downy brome both in very early spring and when new plants germinated in September (Fig. 1, Table 1). Moderate numbers of larvae were also found in very young downy

Table 1.

Percentage of adult *Frankliniella occidentalis* in collections from plants at different stages of growth.

Plant	Type of sample	Number of samples	Total adult thrips	*F. occidentalis* (%)
apple	flowers	116	124	90.3
	shoots	368	932	37.8
dandelion	flowering plants	263	8058	9.1
downy brome	spring plants	126	47	19.5
	fall plants	52	40	20.0
flixweed	prebloom	46	4	75.0
	bloom	20	329	96.4
arrowleaf balsamroot	prebloom	12	2	0.0
	bloom	24	521	47.0
antelope bitterbrush	bloom	32	22	64.3
	shoot growth	176	73	12.3
Gray rabbitbrush	prebloom	84	26	7.7
	bloom	52	967	83.3
snow buckwheat	prebloom	167	12	41.7
	bloom	92	568	86.3
big sagebrush	prebloom	283	113	14.2
	bloom	112	628	89.2

brome.

Flixweed, a yellow-flowered winter annual, was common at the Vantage site. This plant flowered for about six weeks after apple bloom. *Frankliniella occidentalis* was found on the flowers until it was mowed in late May (Fig. 1). Afterward, thrips were less abundant on flixweed and declined until the plant went to seed and dried, around late June.

Dandelion bloom began in April and lasted until frost, but peak bloom occurred in April and early May, declining just before peak apple bloom. Some dandelion plants had over 10 flowers opened at peak flowering. Most dandelions did not produce flowers after May, but about 1% could be found on any one sample date with a single flower until frost. *Frankliniella occidentalis* were present on dandelion before apple trees broke dormancy (Fig. 1). Dandelions sampled from March through the end of apple bloom (mid-May) had a low concentration of thrips, although the flowers were abundant. Some *F. occidentalis* were found in dandelion flowers throughout the growing season, however, other species were more abundant (Table 1), especially *T. treherni*. From mid-May until late September, *T. treherni* were highly concentrated in the few open flowers, with dozens of adults occurring on a single plant. By late summer and fall, very few larvae were found, and thrips populations decreased in October.

Arrowleaf balsamroot began to bloom at this site in early May, and thrips, including *F. occidentalis*, were abundant in the flowers (Fig. 2). Many larvae and a few adult *F. occidentalis* were found on bitterbrush in early May, when the plant was in bloom (Fig. 2). Few thrips were found on the plant as its fruit matured in mid-May to mid-

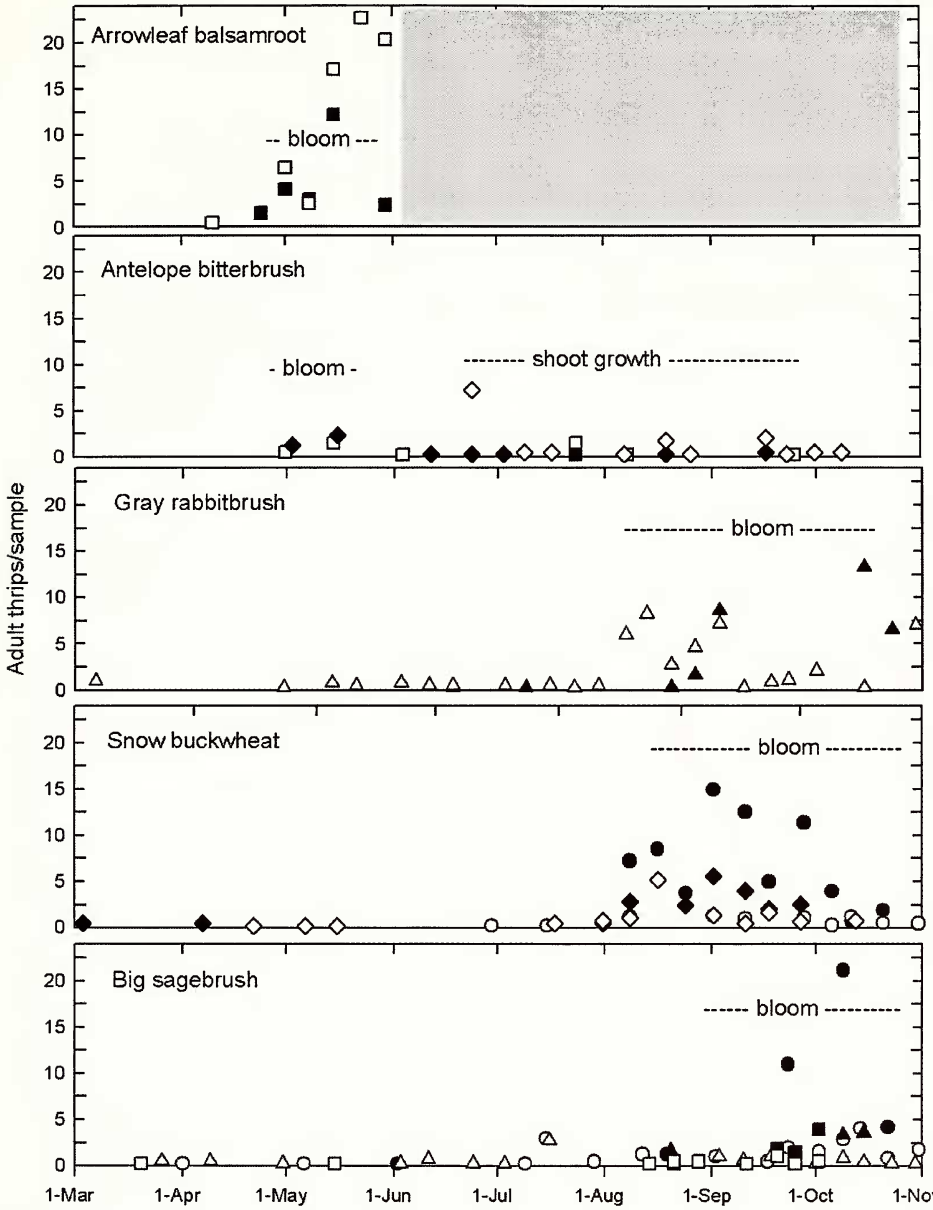

Figure 2. Adult *Frankliniella occidentalis* (solid symbols) and other thrips species combined (open symbols) found in plant samples of native vegetation adjacent to orchards near Brewster (●), Vantage (▲), Bridgeport (■), and Orondo (♦) in 2002. Periods of plant growth are indicated with dashed lines. A gray background shows a period when samples were not taken. Samples with zeros are not represented.

June. When bitterbrush began to grow new vegetative shoots in late June to fall, both adults and larvae were found. These were mostly other thrips species, but a few *F. occidentalis* were collected (Table 1).

Very few thrips occurred on snow buckwheat, big sagebrush, and gray rabbitbrush when shoots were growing in the summer, and those collected were species other than *F. occidentalis* (Fig. 2). Flower heads began to form on big sagebrush in July, and by September and October, thrips were abundant on the open flowers. Adults were found first, followed by larvae 1-2 weeks

later. Gray rabbitbrush and snow buckwheat also attracted thrips to their flowers, including *F. occidentalis* (Fig. 2, Table 1). Native grasses such as bluebunch wheatgrass, sandberg bluegrass, and needlegrass had very few thrips and no *F. occidentalis* were collected.

DISCUSSION

In Washington, *F. occidentalis* was the most numerous adult thrips and was most likely the predominant species ovipositing in apple flowers. They produced most of the fruit injury, and the abundant larvae found at king bloom and later. Thus, orchard management aimed at reducing numbers of this species is key to minimizing pansy spot. *A. obscurus*, also recovered from apple flowers, is a specialist on grasses (Lewis *et al.* 1997b) and highly unlikely to oviposit in apple blossom clusters. *Thrips brevipilosus*, rare in our samples, has not been collected on apple previously and may have been reproducing on weeds (Moulton 1927).

Frankliniella occidentalis is considered to be highly nomadic (Terry 1997) and movement from plant to plant likely explains much of the fluctuations in population density. The sequence of movement in apple orchards can be inferred from the phenology on individual hosts. *Frankliniella occidentalis* overwinters as mated adult females in leaf litter and on the bark of trees (Pearsall and Myers 2000a). Adults begin emerging in early March and continue emerging for six weeks (Pearsall and Myers 2000a). In Washington orchards, the earliest plants attractive to adults include downy brome and dandelion. As soon as apple trees begin to grow, they attracted a few adults to flowering as well as vegetative buds. Adults concentrated in apple flowers after the petals began to open, the corolla colour changed from pink to pink and white, and flowers released fragrance. Adults of this anthophilous species were most likely drawn to apple and other host flowers based on a combination of colour and fragrance (Terry 1997). In addition, the magnitude and timing of migration to apple flowers may have been in response to temperature (Pearsall and Myers 2000a).

After petal fall, *F. occidentalis* adults joined a mixture of species in apple shoots from early spring until late summer. This season-long presence on apple trees, although alluded to by Venables (1925), has gone largely ignored and unstudied since that time. Adults can also move to flixweed when it flowers briefly after apple bloom from mid-May to mid-June, or return to dandelion, which maintains limited flowering throughout the summer and fall. *Thrips trehernei* was the most common species on dandelion in Washington, echoing the findings in British Columbia (Madsen and Jack 1966, Pearsall and Myers 2001). In early fall, *F. occidentalis* adults can move to young downy brome. Thus, *F. occidentalis* can continuously inhabit apple orchards.

All plant species selected for sampling in the sagebrush-steppe habitat, except the grasses, had *F. occidentalis* adults present, especially during bloom. *Frankliniella occidentalis* has been collected on almost every flower sampled from western orchards and surrounding vegetation (Madsen and Jack 1966, Pearsall and Myers 2000a). Thrips can probably find open flowers or growing shoots throughout the year in native vegetation because of the diversity of plant species and their different growth habits. There are a few gaps in the phenology of plants sampled in this study when concentrations of *F. occidentalis* adults could not be located, namely March to early April, and June through July. Some common species not sampled were observed blooming in March, such as bluebell, *Mertensia longiflora* Greene, and sagebrush buttercup, *Ranunculus glaberrimus* Hook. Plant species other than those sampled in our study could be found blooming in June and July, such as lupin, *Lupinus* spp., and desert buckwheat, *Eriogonum* spp., and could be important in the population dynamics of *F.*

occidentalis. Pearsall and Myers (2001) caught most *F. occidentalis* on sticky cards placed in sagebrush steppe during March, late April to early May, and again in September. Two of these periods correspond to the blooming of arrowleaf balsamroot and big sagebrush, which may be the cause of increased flight or abundance. Thus, much of the population dynamics can be inferred by plant to plant movement within this habitat.

The possibility remains that *F. occidentalis* migrates between native, dry habitats and orchards during periods of sparse shoot growth or bloom. For example, fruit trees appear to attract thrips into orchards in spring (Pearsall and Myers 2001). Alternatively, the woody species big sagebrush, gray rabbitbrush, and snow buckwheat, which had a high concentration of *F. occidentalis* adults in their flowers, may attract *F. occidentalis* out of orchards when in bloom in the fall. Migration in and out of orchards has not been studied and remains critical to understanding the phenology and population dynamics of this species.

Reduction of weedy hosts has been suggested as an integral part of management of *F. occidentalis* in orchards (Venables 1925). However, our samples indicated relatively low numbers of thrips in two abundant weeds, downy brome and dandelion, before apple bloom. The apple trees themselves harboured adults throughout the growing season, as did numerous other plant species in and adjacent to orchards. Thus, indirect management of this pest through reduction of any one plant species may prove challenging.

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